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# Omnidirectional Waveguide Slot Antenna for Horizontal Polarisation Part-1

Onidirectional antennas are used in telecommunications when it is desired to transmit (or receive) in several directions or when the heading of the other station is unknown. The latter occurs in amateur operation when calling CQ and particularly during contest operation.

The largest use of omnidirectional antennas is in mobile and portable operation, where the use of beam antennas would be impractical on account of their dimensions. In this case vertically polarised aerials are used, being the simplest to realise, from shortened rods through half-wave dipoles to stacked dipoles (mainly at fixed stations).

For operation in horizontal polarisation, especially DX and contest traffic, use is commonly made of beams which are stacked or bayed in the elevation and azimuth planes in order to achieve gain, for instance stacked Yagis and two-dimensional arrays.

In situations where weak signals can be received only on the main lobe of a narrow beam, an omnidirectional antenna with high gain would be highly desirable. In contests this would enabled the band to be searched with the omni antenna and once a station was found, then switch to the beam antenna to raise the signal out of the noise and make the QSO. In this kind of antenna diversity there appears to be a gain difference of about 5 to 10 dB between omni and rotatable beam antennas. So with the commonly used small-to-medium antenna system with a gain of 20dB this would represent a difference of the order of 10 to 15dB.

Another important application for omnidirectional antennas with high gain is horizontally polarised repeaters (such as amateur television) and beacons. On the microwave bands these use stacked radiators of the "Big Wheel" variety, which all the same present problems, both mechanical (size) and electrical (feeding). In

addition they are not easy to fabricate or maintain.

On the other hand slot antennas (Ref.1) can be used. The dimensioning of these invites dimensioning errors, however, with the result that the chosen slot arrangement does not give the omnidirectional characteristic expected. Furthermore a "round" radiation pattern can only be achieved with flat waveguide. Since the omnidirectional slot-radiator antenna appears in principle to be very suitable for amateur purposes it was decided to research this type of aerial some more. The aim was to develop a mechanically and electrically foolproof realisation that was cheap and achievable with amateur resources. Significant research on dimensioning and the development of a sample antenna for the 23cm band was carried out as a diploma task in the antenna laboratory of Telefunken in Ulm, Germany. The following is an outline of the theoretical basics and the concept of the antenna arrangement.

At the same time approximation formulae are given for the maximum permissible number of slots and the achievable lobe width/gain. The dimensioning of the slots is described in sufficient detail for individual variations to be considered. Finally we describe the dimensioning, production and test results for 23cm and 13cm antennas.

## 1. CONCEPT OF THE WAVEGUIDE SLOT ANTENNA

The configuration shown in Fig.1 lends itself to an application needing an omnidirectional antenna with horizontal polarisation and a narrow vertical (elevation) radiation pattern with high gain. Here a waveguide is erected vertically with slots running also vertically.

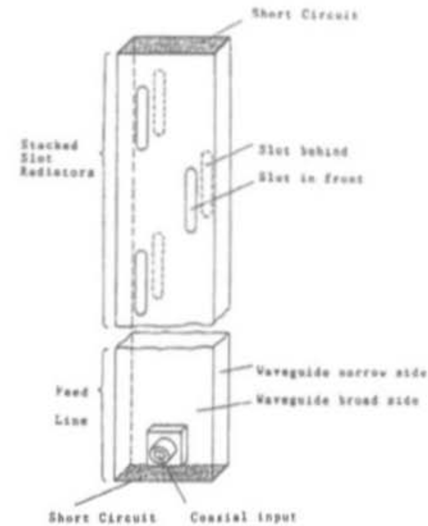


Fig.1: Waveguide Slot Antenna for omnidirectional radiation

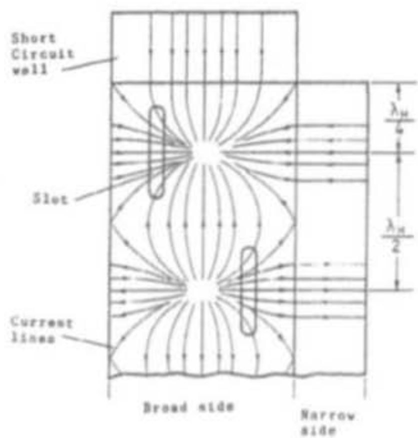


Fig.2: Sketch of the current flow lines in a waveguide slot antenna. View of broad side; the narrow side and short circuit are drawn as if they have been folded back.

The slots lie opposite one another on the front and rear broad sides, arranged either side of the centre line. The waveguide is short-circuited a quarter wavelength beyond the last slot. The inter-slot distances along the waveguide are half the wavelength of the waveguide. The antenna is fed via a coaxial-to-waveguide transition at the bottom end of the waveguide.

The mode of operation of the antenna goes under the name of "Resonant Array". In the absence of the slots a standing wave would occur in the whole waveguide (the end is short-circuited!). The current distribution resulting on the inner side of one of the broad sides from this is sketched in Fig.2.

At a distance of a quarter waveguide wavelength ($\lambda_H/4$) from the short circuit, the current follows a purely transverse direction and at the same time the current component disappears in the axial direction. The pattern of the current repeats itself exactly at distances of a half waveguide wavelength, however with the mathematical sign reversed. Equally, on the opposite side of the waveguide the same current distribution occurs, only in the reverse direction, that is with the mathematical sign reversed.

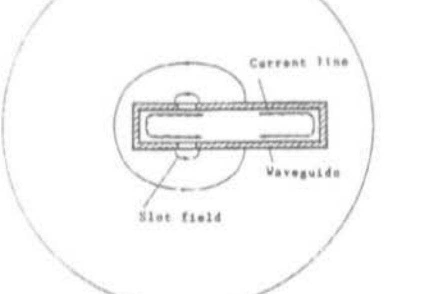


**Fig.3: Excitation and radiation from opposed slots in the broad side of the waveguide.**

Slots in the wall of the waveguide interrupt the flows; the currents flowing vertically excite electrical fields vertically over the broad side of the slots. This can be seen as the source of radiation into free space.

For vertically-arranged slots to produce horizontal radiation we need to find the locations where the currents in the wall of the waveguide are flowing horizontally. In this, the distance from the centre-line of the waveguide determines the "strength" of the power that can be decoupled, since the horizontal flow components increase towards the sides (they are zero at the exact centre).

The interlacing of the slots about the centre line is necessary to equalise the sign-reversal of the current flows in the wall of the waveguide. In this way we can arrange a vertical stacking of slots which will produce excitation in equal phase and thus produce the narrow beamwidth and hence increased antenna gain desired. The more slots, the narrower the beam and hence the higher the gain.

As an approximation, the lobe width in the elevation [delta theta] is determined by the length of the radiating part of the antenna, i.e. the number of slots N and the stacking distance $\lambda_H/2$,

$$\Delta\theta \approx 50.7° \cdot \frac{\lambda_0}{N \cdot \lambda_H/2} \qquad \text{(Gl. 1)}$$

in which $\lambda_o$ is the free-space wavelength and N the number of slot-pairs.

Correspondingly, the antenna gain is given, by way of approximation, as

$$G \approx N \cdot \lambda_H/\lambda_0 \qquad \text{(Gl. 2)}$$

Unfortunately for practical constructions we cannot increase the number of slots ad lib. since the usable bandwidth of the antenna decreases with the number of slots. This effect is due to the production of a standing wave and resembles the behaviour of a resonator.

In an approximate fashion the number of slot-pairs is limited by the increasing mismatch and deformation of the radiation diagram at the frequency band edges as follows:

$$N_{max} \approx 100 \cdot \frac{0.5}{\Delta f / f_0} \qquad \text{(Gl. 3)}$$

wherein $N_{max}$ is the highest number of slot-pairs usable in an antenna with a frequency bandwidth of delta f and a centre frequency of $f_0$.

The slots are dimensioned so that at the design frequency, the standing wave from the upper short circuit fades away at the lowest slot, which means the antenna is matched ahead of the first slot. The waveguide is matched at the transition to coaxial feeder and thus the length of this feeder region can, with due regard to material and fixing considerations, be of any length, allowing the waveguide to be used simultaneously as a mast and reducing the length of coaxial feeder.

The placing of the two opposing slots represents a special problem. Fig.3 demonstrates why in contrast to (1) the slots should lie directly opposite one another.

For the production of a closed, ring-shaped line of the electrical far-field, both slots must present opposing fields as they would excite at directly opposite locations on account of the natural current flow in the waveguide wall.

A further factor in ensuring the electrical far-field line has an equal field-strength is that the waveguide should be as flat as possible, that is the narrow side should be as small as possible. In (3) it is shown that below a height of the waveguide of about 0.15 wavelength (about half the standard height of waveguide) the circular diagram shows a ripple below 1dB (that is deviations from the ideal constant field strength along the far-field line).

For the realisation of antennas with amateur means this is no problem, however. If expensive precision waveguide with half-standard height is unavailable, cheap aluminium extrusions can be used, and despite their dimensional tolerances they can be used as flat waveguide in the lower microwave bands.

## 2. DIMENSIONING THE SLOTS

Dimensioning uses the equivalent circuit set out by Silver (4).

A single longitudinal slot in the broad side of a waveguide can be represented as a complex

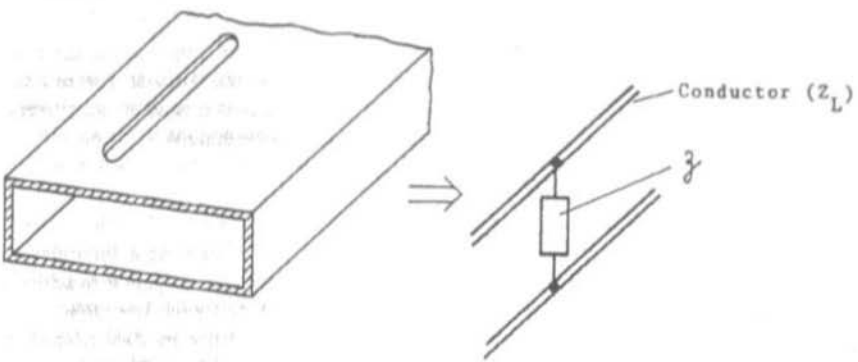


**Fig.4: Equivalent circuit of a lengthwise slot in the broadside of the waveguide**

impedance Z parallel to the conductor (Fig.4). From this equivalent circuit results the common description "shunt slot". With a slot length of approx. $\lambda_0/2$ the imaginary component becomes zero and the slot is in resonance. The real component of the slot impedance representing radiation of power into free space is calculated according to Silver as:

$$\frac{Z_L}{R} \approx 2.09 \frac{\lambda_H a}{\lambda_0 b} \sin^2\left(\frac{\pi x}{a}\right) \cos^2\left(\frac{\pi \lambda_0}{2 \lambda_H}\right) \quad \text{(Gl. 4)}$$

In the above $\lambda_H$ is the waveguide wavelength, $_0$ the free-space wavelength, a x b the cross-section dimensions of the waveguide and x the centre-line of the slot. The following are also valid:

$$\lambda_H = \lambda_0 / \sqrt{1 - (\lambda_0/2a)^2} \quad \text{(Gl. 5)}$$

$$\lambda_0 \,[\mathrm{mm}] = 300/f \,[\mathrm{GHz}] \quad \text{(Gl. 6)}$$

$Z_L$ is the reference resistance of the waveguide, and through the quotient formation of $Z_L$ and R the normalised slot conductivity is formed. The arguments of the angle functions are drawn as a circular measure, so corresponds to 180 degrees. In the case presented here of the double slots in a flat waveguide (with height about a quarter of the width) the two slots work out almost as an ideal parallel circuit, in which the normalised slot conductivity is doubled. The best agreement of the results from a series of measurements is achieved with the following equation, modified correspondingly from equation 4.

$$\frac{Z_L}{R} \approx 3.5 \frac{\lambda_H a}{\lambda_0 b} \sin^2\left(\frac{\pi x}{a}\right) \cos^2\left(\frac{\pi \lambda_0}{2 \lambda_H}\right) \quad \text{(Gl. 7)}$$

To use these dimensioning measurements in antennas with several elements or slot-pairs it is important that the coupling of the slots along the waveguide axis is sufficiently small that the characteristics of the slots even in large groups (many slot-pairs) are worked out sufficient for our purposes according to equation 7.

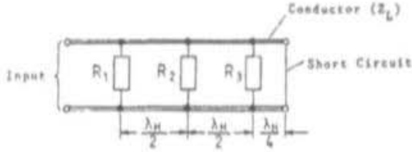


**Fig.5: Antenna with 3 slots as an example for calculating input resistance.**

Still missing for dimensioning the antenna is a determination of the centre line offset of the slots and their length.

To achieve the maximum possible gain all the slots should be driven at resonance at the design frequency of the antenna. This means the impedance of the slots could be replaced by the appropriate real component (resistance R). Moreover at this frequency the slots lie exactly half a waveguide wavelength apart and the final slot is exactly a quarter wavelength ahead of the short circuit (Fig.5). In this example the short circuit transforms itself into an open-load parallel to the last slot resistance, this last resistance transforms itself without alteration parallel to the next-previous resistance, and the parallel circuit of these both transforms itself without alteration parallel to the first resistance. That means that all slot resistances at the design frequency are connected in parallel, i.e. their conductivities add up.

To achieve matching at the entry to the group of slots it is necessary that the resulting resistance of the slots is equal to the reference resistance of the feedline.

$$Z_L = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \quad \text{(Gl. 8)}$$

For our application there is a simplification that the maximum antenna gain is to achieved with a given number N (equation 3) of slot-pairs. All slot-pairs are dimensioned the same with the slot resistance R

$$\frac{Z_L}{R} = \frac{1}{N} \qquad \text{(Gl. 9)}$$

With this result the slot centre line offset from equation 7 can be calculated.

**Example:**

The waveguide cross-section dimensions are a x b = 172mm x 42mm, wall thickness 4mm, frequency $f_0$ = 1.27GHz, N = 12 slot-pairs.

Equation 9 gives $Z_L/R$ = 1/12 = 0.083
Equation 5 gives $\lambda_H/_0$ = 1.3765

With equation 7 the course of the normalised slot conductivities is calculated as a function of the slot centre line offset and as Fig.6 represents graphically. We are looking for the value of x which takes the value of 0.083 for the function, namely x = 8.6mm.

The slot length for resonance for the slot-pairs under discussion lies close to $\lambda_0/2$, however, there are dependencies on frequency, the wall thickness and height of the waveguide and above all, the centre line offset of the slots. Moreover, the shape of the ends of the slots plays a role: the rectangular slots with straight ends normally researched in the literature can scarcely be made in practice. The easiest way of making slots is from above with a milling cutter whose diameter corresponds to the width of the slot; the entry and exit points at the end of the slots will therefore be semi-circular.

The slot lengths finally resulting for resonance must be determined experimentally for the waveguide in use and the frequency region of interest in conjunction with the width and the form of the ends of the slots. Fig.7 shows the result for the waveguide in the first example. The slots are produced with a milling cutter of 10mm diameter, although good results approximating to these were also achieved with slots 50 per cent wider or narrower. The graphic also shows the slot length formed on the free-space wavelength $L/\lambda_0$ (from end to end) as a function of the slot centre line offset x. The central solid line curve is valid for the design frequency $f_0$ = 1.27GHz, while the pecked curves give the frequency-dependence results for 5 per cent higher or lower frequency.

With this representation the length necessary for slots dimensioned in the example can be found.

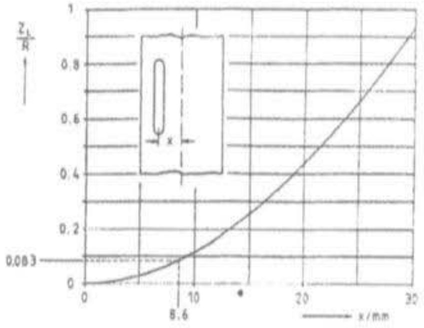


**Fig.6: Representation of the normalised slot transverse conductor value as a function of the slot centre partition for the geometry in example 1.**

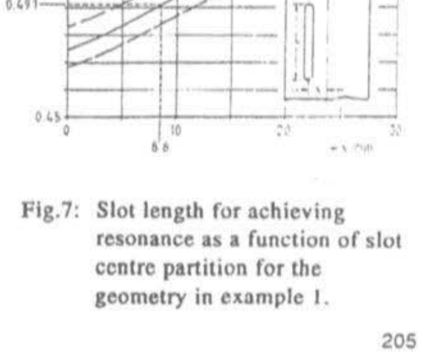


**Fig.7: Slot length for achieving resonance as a function of slot centre partition for the geometry in example 1.**

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# Omnidirectional Waveguide Slot Antenna for Horizontal Polarisation Part-2 (conclusion)

## 3. ANTENNA FOR THE 23CM BAND

The requirement is an antenna that covers the complete 23cm band with the highest possible gain in the azimuth plane (horizontally).

With the help of a simulation (S-Compact) for matching and slot voltages and the additional simulation of the antenna diagram, an investigation was launched into how many elements should be used. To begin, equation 3 produces a maximum of 10 slot pairs with f = (1.3GHz - 1.24GHz) and $f_0$ = 1.27GHz. The simulation process indicated, however, that even with 12 slot pairs, VSWR did not pass significantly above 2 except at the extremes of the band. At the same time the beam squints downwards by about 1 degree at the bottom end and by the same amount upwards at the top end of the band. The related drop in gain including losses due to mismatching is about 1dB, whereas 12 $dB_i$ is achieved in the centre of the band.

The antenna as completed is shown in Fig.8. For the waveguide a rectangular pipe 180 x 50 x 4mm (externally) to DIN 1770 standards is used (the material is AlMgSiv 0.5 F22); this is widely used as an extruded profile in mechanical construction. Producer is the company Wieland in Ulm, price about £7 per metre, maximum length 6 metres.

A flange is applied to the top end and screwed tight to form a short-circuit. Here at Telefunken we used a special salt bath welding process but for amateur technology a simple piece of sheet metal short-circuit will suffice, either screwed on or attached with conductive fastener (Fig.9).

The centre offset and length of the slots correspond with the results from examples 1 and 2. The distance of the slots from half or quarter of a wavelength of the waveguide (for short-circuit) were calculated with equation 5 for a centre frequency of 1.27GHz.

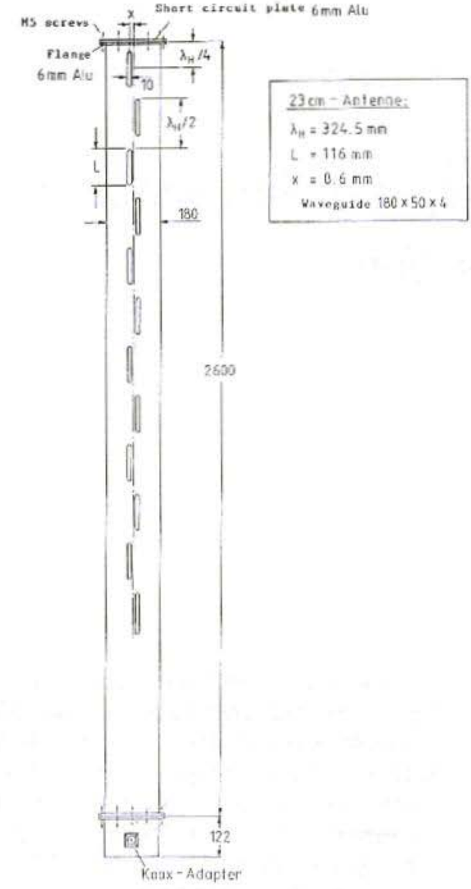


Fig.8: Construction of the 23cm Antenna with 12 pairs of slots

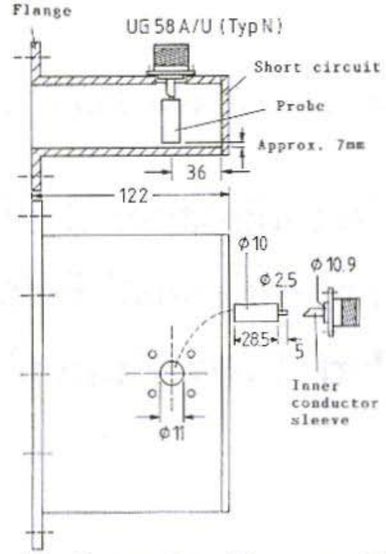


Fig.10: Construction of the waveguide to coax transition of the 23cm antenna

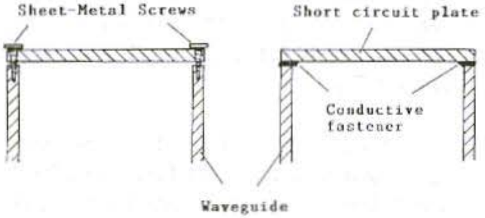


Fig.9: Alternative possibilities for fastening the short circuit plates with screws or conductive fasteners

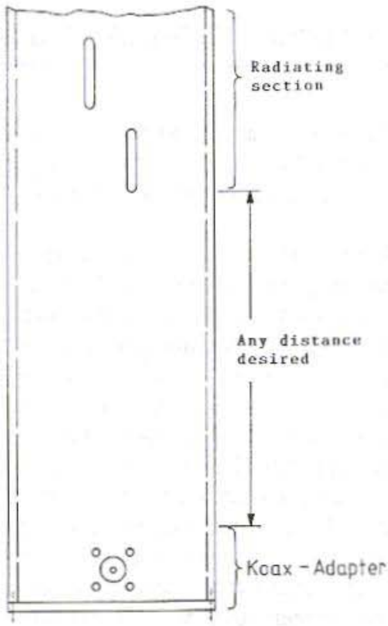


Fig.11: Integration of the coax adaptor without flange connection

Below the last slot there is a conductive section of about 65cm to a waveguide-to-coax transition at the end of the waveguide. The transition is made as shown in Fig.10, with a coupling probe protruding into the waveguide about an eighth of a wavelength from a short-circuit. The coupling probe comprises an N-connector with extended centre conductor. The connector is turned on the flange side around the outer coaxial conductor so that it can fit in a corresponding hole in the broad side of the waveguide. The inner conductor made into a sleeve is lengthened with brass circular section soldered onto it.

The dimensioning of this transition with its thickened probe and its short distance to the waveguide short-circuit is at variance with the conventional construction methods which use thin probes and a quarter waveguide wavelength distance. At the same time the matching bandwidth is well below the size of the full waveguide transitions, but with careful adjustment the complete 23cm waveband is achieved, with reflections attenuated by 30dB.

The transition can also be integrated directly into the antenna waveguide without a waveguide to flange connection (Fig.11). The antenna is then made up only of a single piece of waveguide with milled slots and the coaxial adapter together with a short-circuit plate at each end.

The complete antenna demonstrates the expected matching characteristic (Fig.12) with a VSWR less than 2 up to approaching the band ends and with the best match at the centre of the band. The radiation diagram (Fig.13) shows in the horizontal plane a variation of plus or minus 1.3dB. In elevation the first side-lobes appear at -13dB, as expected with an antenna with constant element levels, and the 3dB beamwidth is 6 degrees.

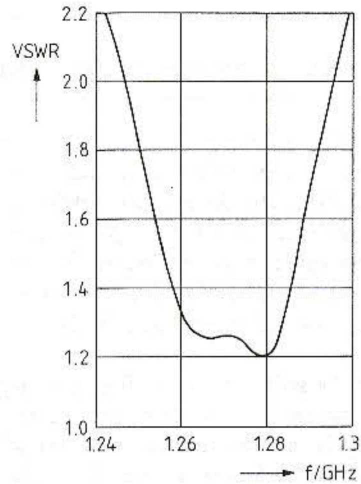


**Fig.12: Measured SWR of the 23cm Antenna as a function of**

The expected slight deviation of the beam (squinting) on leaving the centre frequency and the gain values given above were achieved with close approximation.

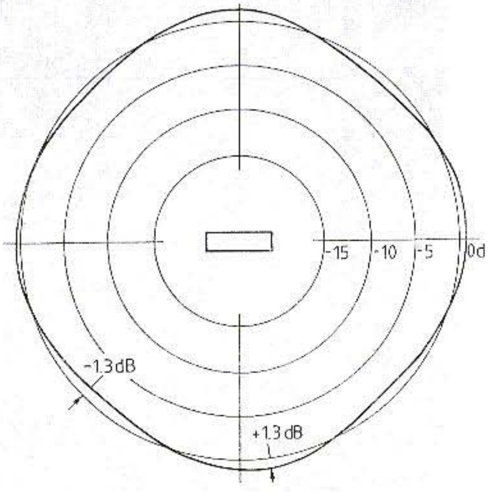


**Fig.13: Measured Circular radiation diagram of the 23cm Antenna**

## 4.
## ANTENNA FOR THE 13CM BAND

An ATV repeater required a horizontally polarised omni aerial on a frequency of 2392.5MHz. The dimensional details of the 23cm antenna can be scaled up if use is made of a waveguide cross-section which has been scaled down by the frequency relationship (the factor is 1.27 divided by 2.3925).

Sadly, the series of flat profiles according to DIN standard 1770 does not contain a rectangular section close to the result of the calculation performed on the 23cm profile. Therefore recourse was made to welding together two aluminium angle sections. Our limited production facilities were able to make

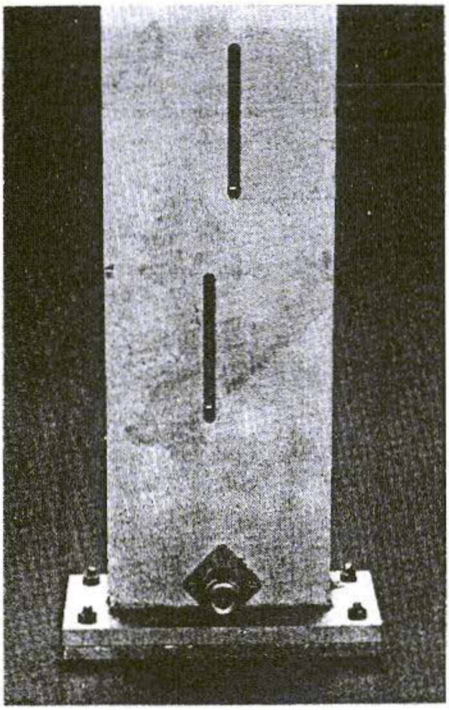

**Fig.14: Photograph of the 13cm Antenna with 9 pairs of slots**

a waveguide with the exact dimensioned cross-section of 86 x 21mm, but only in lengths of 900mm maximum.

With this length only nine slots can be undertaken and the slot dimensions must be re-calculated. The dimensioned slot conductor value according to equation 9 rises to:

$$Z_L/R = 1/9 = 0.111$$

Thanks to the exact scaling of the waveguide cross-section, the relationship of side a to b and the waveguide's wavelength to the free wavelength remain exactly as with the 23cm antenna. So the offset of the slot centre can be as in Fig.6 again. From Fig.6 we read off first $x = 9.75$mm for $Z_L/R = 0.111$. With the scaling factor we get:

The slot length can also be taken from the corresponding 23cm drawing; Fig.7 gives initially for x = 9.75mm the dimensioned slot length L/[lamda zero] = 0.494. At the design frequency the slot length thus becomes:

Incidentally the slot distances and the short-circuit distance emerge with the scaling factor from the corresponding values of the 23cm antenna. Because a 5mm tool was available conveniently, the slots were milled with this width.

Fig.14 shows the resulting antenna. The transition to coaxial conductor at the bottom end of the antenna is once more made with an N-connector and an extended probe. While the dimensions of the probe could be reduced to some extent by the scaling factor, the measurements of the connector itself naturally could not be changed. The cross-section of the coaxial line (connector) have only slight influence on the characteristics of the transi-

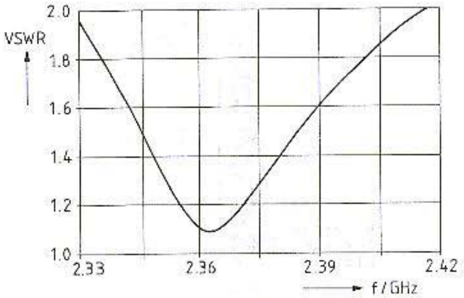


**Fig.15: Measured SWR of the 13cm Antenna as a function of Frequency**

tion, but on higher bands a smaller connector (for example an SMA) should be used in order to scale the relationships more closely. The short-circuit at the bottom end of the waveguide is brought closer according to the scaling factor on the 23cm dimensions.

Measurement of the input matching of the antenna (Fig.15) shows a satisfactory match, though slightly shifted from the desired frequency - a sign that the rescaling was not 100 per cent successful. The elevation radiation characteristics (Fig.16) display a beamwidth of around 8 degrees and between 13 and 14dB suppression of side-lobes. The measured antenna gain is around 10.4dB[i], within a few tenths of a dB of the theoretical value for the loss-less situation.

## 5. PRACTICAL EXPERIENCE

During 1989 and 1990 DG8SG/P was active from locator JN58BH in a number of contests and QRV on 23cm with SSB in BBT.

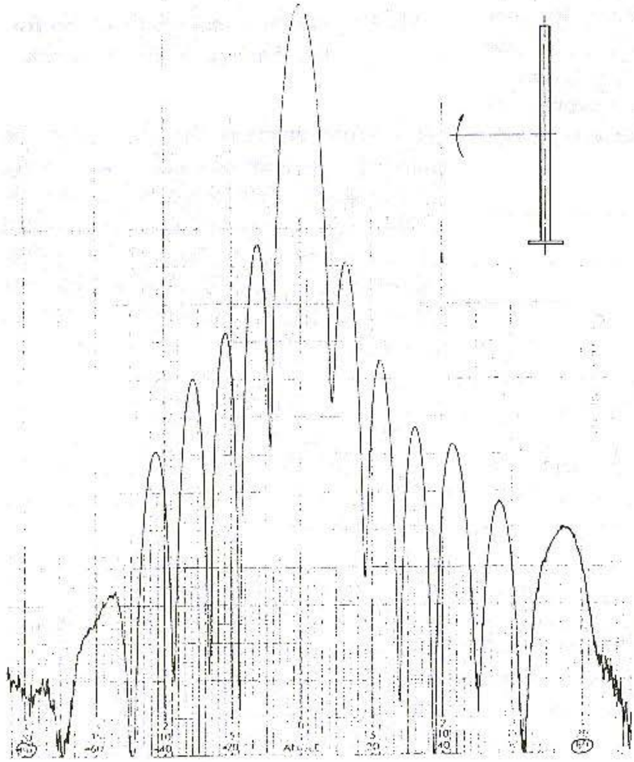

**Fig.16: Measured elevationradiation diagram of the 13cm Antenna between -90 degrees (vertical to the ground) and +90 degrees (vertical upwards)**

The matching he measured through cable losses of the feeder (1dB) appeared better than as measured in the laboratory.

As reference antenna a 23 element Yagi with 18.5dB[i] gain was available, fed via 10 metres of 5/8'' Flexwell cable. the omni aerial was connected to the transverter through 3.5 metres of RG-214 and a coaxial switch, enabling rapid selection of either antenna. On receive the Yagi showed an advantage (about 4 or 5dB) but only when it was accurately beamed. On transmit most stations reacted positively when both antennas were used (''the omni works fine'').

The 23cm and 13cm antennas were tested out on FM-ATV at the weather station tower of Gundremmingen power station (JN58FM). After solving problems of transport (the lift) and mounting (narrow platform) -the long 23cm antenna caused particular grief - the results were very satisfactory and got enthusiastic reactions (significantly improved picture quality over the original antenna system).

## 6. OUTLOOK

The experimental results support the validity of the dimensioning work. One can expect then that other, divergent sizes of antenna will be built. All the same, with slot totals significantly more than 12, a narrow bandwidth must be reckoned with and fine tolerances of waveguide size and slot distances will lead to frequency shifts. With amateur production methods antenna sizes of more than 20 to 25 elements should not be exceeded (approx. 3 degrees beamwidth). Smaller totals of slots will produce more broadbanded antennas and uncritical dimensional tolerances.

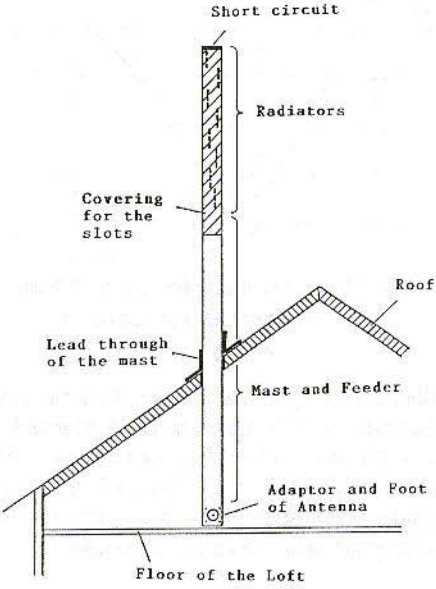


**Fig.17: Practical mountingmethod for the Waveguide Slot Antenna**

For outdoor antennas the slots must be protected, to prevent rain and snow entering the waveguide. Thin self-adhesive tape is suitable, e.g. Scotch Invisible tape, wound around the waveguide. The negligible thickness of normal tape will have no detectable influence on the slot characteristics at these frequencies.

Alternatively thin-walled plastic piping with low RF loss can be used to make a radome; suitable pipes will be difficult for amateurs to obtain and will additionally need its own method of fixing.

In both cases some ventilation is necessary at the bottom of the antenna to equalise air pressure and let out moisture.

Mounting can achieve an elegant unit of support mast, feedline and radiator all combined. This involves selecting a sufficient

length of waveguide that will hold the radiating section (the slots) high enough, while the lower end with the coaxial input forms the lower fixing point or standing foot, as seen in Fig.17. In this way no separate feeder is required from the foot of the mast to the radiators: the extremely low feed loss of the waveguide at less than 0.1dB per metre could scarcely be achieved with coaxial cable!

In this form the antenna requires no bearer mast. On the contrary, the security of the rectangular pipe of the 23cm and 13cm versions should be sufficient to carry further antennas at the upper end. Their coax feeders can be led up the narrow side of the waveguide without problem and small screws and clips for fixing can be kept away from the radiating slots.

## 7. LITERATURE


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